



# Evaluation of an Airborne Spacing Concept to Support Continuous Descent Arrival Operations

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# *Why CDA?*



Continuous Descent Arrivals, aka Optimal Profile Descents, offer improvements in fuel efficiency, flight time and noise reduction.

The freedom to optimize each aircraft reduces the controller's ability to manage the aircraft.

Additional spacing is often added to protect against this variability.

This limits their usefulness to low-demand environments.



# *Why Airborne Spacing?*

Airborne spacing makes use of airborne surveillance, ADS-B In, to allow the aircraft to manage their spacing relative to another.

The aircraft can make small speed variations to stay close to their optimal profile while meeting the controller's spacing goal.

Can this be done efficiently?

# Merging and Spacing



## Merging and Spacing Working Group

Started in 2005

Sponsored by FAA, includes MITRE, NASA, UPS, others

Develop scheduling and airborne guidance tools to provide efficient flow and flights

Focus on high-demand, medium-complexity airport

## Current implementation is being tested at SDF

Unidirectional flow using one arrival route

Limited number of equipped aircraft and trained crews

Airline-based sequencing and scheduling

## Future implementation

Several arrival routes to multiple runways

Dependent parallel arrivals

ATC-based sequencing and scheduling

# *NASA's Airborne Precision Spacing*



NASA Langley has been developing and testing a trajectory-based spacing concept and prototype tool for several years.

Previous batch and human-in-the-loop simulations have shown a delivery precision of 2-5 seconds (standard deviation) at the runway threshold.

Spacing tool needs to know assigned route and planned final approach speed for both aircraft.

An on-condition ADS-B report provides this information

Trajectory-based approach allows spacing to begin well before aircraft are in trail.

# *Merging and Spacing Evaluation*



The goal was to study the trajectory-based spacing tool in an initial M&S environment under normal and off-nominal ATC events.

The off-nominal ATC events include:

- Vectoring during descent

- Speed intervention

- Large spacing error at initial set-up

# *Experiment Objectives*



Determine completeness and acceptability of pilot procedures

- Questionnaires provided after each run

- Workload measured with MCH rating scale

Evaluate use of pilot procedures

- Missed or incorrect steps

- Undesirable aircraft maneuvers

Evaluate the spacing performance

- Delivery accuracy and precision

- Fuel and time impact

# *Experiment Design*



8 “crews” per scenario

8 scenarios per group

3 groups

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192 data points

7 PC-based, single pilot workstation simulators

1 full-workload, two-crew, fixed-based simulator

Same aircraft type – narrow body, twin engine  
transport



# Simulators

## Integration Flight Deck (IFD)

Full workload simulator

Two crew members

Out-the-window visuals



## Aircraft Simulator for Traffic Operations Research (ASTOR)

PC-based, mouse-driven simulator

Single crew member interface

Interface and displays based on modern Boeing glass cockpit

# Participants



26 active commercial pilots from major US air carriers.

Average age:  $48 \pm 6$  yrs

Average experience:  $18.7 \pm 7.8$  yrs

22 B-777; 7 B-767; 2 B-747; 1 B-737

2 retired controllers worked en route and approach control as confederates

Provided clearances and hand-offs

Familiar with the Merging and Spacing operations



# Scenarios

All A/C direct ENL or PRINC  
 T/D just before PRINC  
 #1 and #6 flies standard CDA  
 Gap between #5 and #6  
 ATC vector for one aircraft at  
 either FL240 or FL180; 5 nm  
 off-path  
 ATC speed intervene at FL180;  
 resume before CBSKT

## RC Special Procedure: Louisville PDS CDA

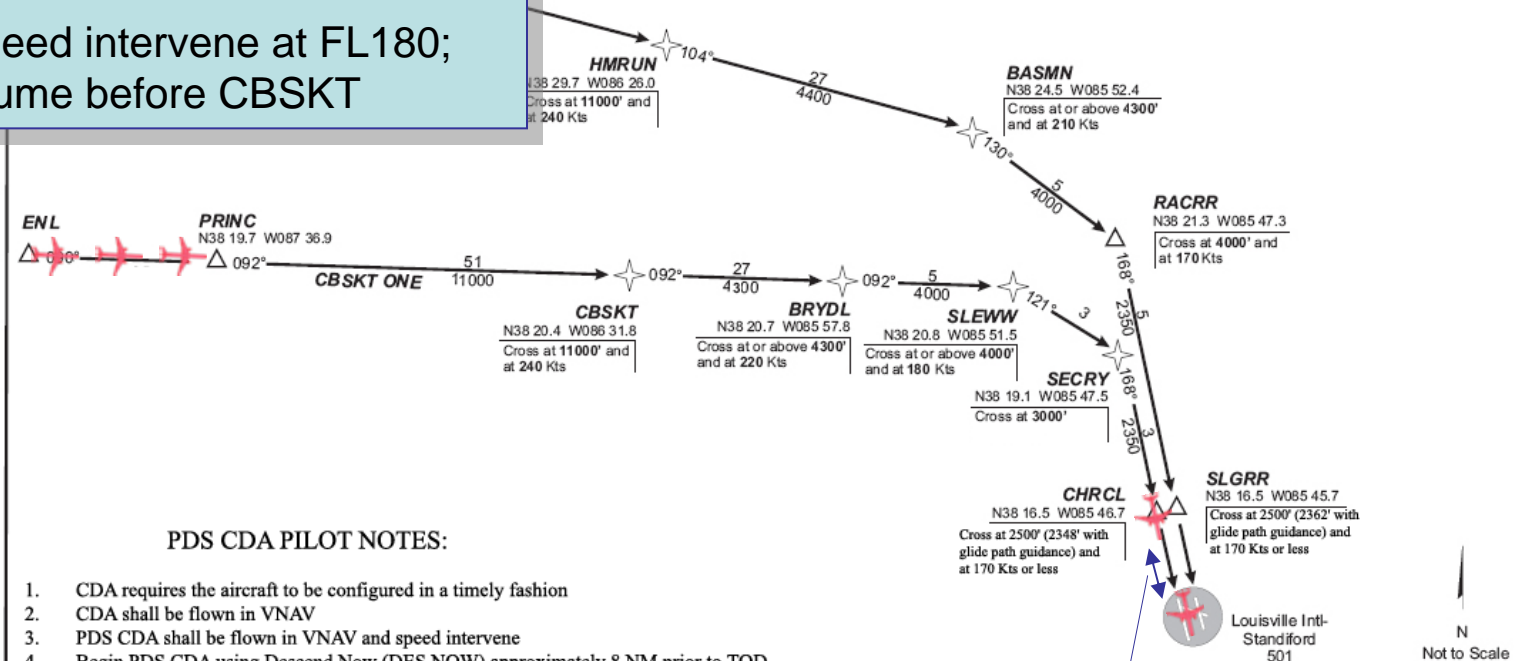
10-2T1

CDA ARRIVALS

LOUISVILLE, KY

LOUISVILLE INTL-STANDIFORD

CDA SOUTH ARRIVALS  
 CALKS ONE ARRIVAL (CALKS1)  
 SEA BISCUIT ONE ARRIVAL (CBSKT1)



### PDS CDA PILOT NOTES:

1. CDA requires the aircraft to be configured in a timely fashion
2. CDA shall be flown in VNAV
3. PDS CDA shall be flown in VNAV and speed intervene
4. Begin PDS CDA using Descend Now (DES NOW) approximately 8 NM prior to TOD
5. CALKS ONE - Expect ILS 17L, CBSKT ONE - Expect ILS 17R
6. Set the FMS descent speed to CRZ MACH/310
7. Set MCP altitude window to the lowest assigned ATC altitude
8. PDS guidance supersedes charted speeds
9. Maintain speed  $\pm 5$  knots IAS of published or PDS speeds
10. Once established in descent maintain vertical path within  $\pm 400$  feet
11. Select initial flaps no later than BRYDL or BASMN
12. Select gear down and approach flaps no later than 1 NM prior to CHRCL or SLGRR
13. After capturing the localizer, fly path or glide slope to the FAF
14. Flaps 30 landing is required for data collection purposes

150 sec

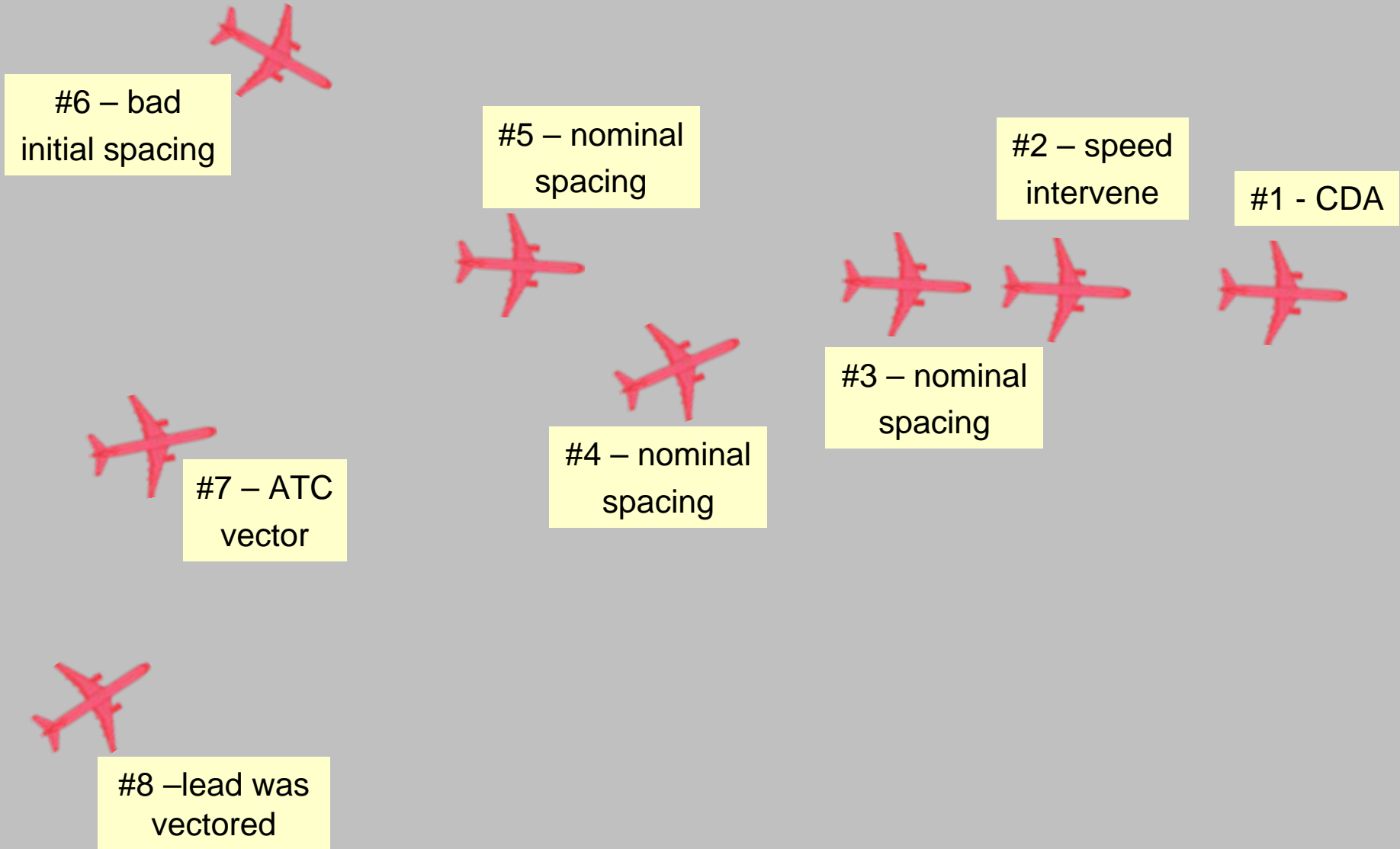
### Nominal conditions:

50% wind forecast error  
 initial spacing deviation  $\pm 30$  s  
 35-50 min flight time

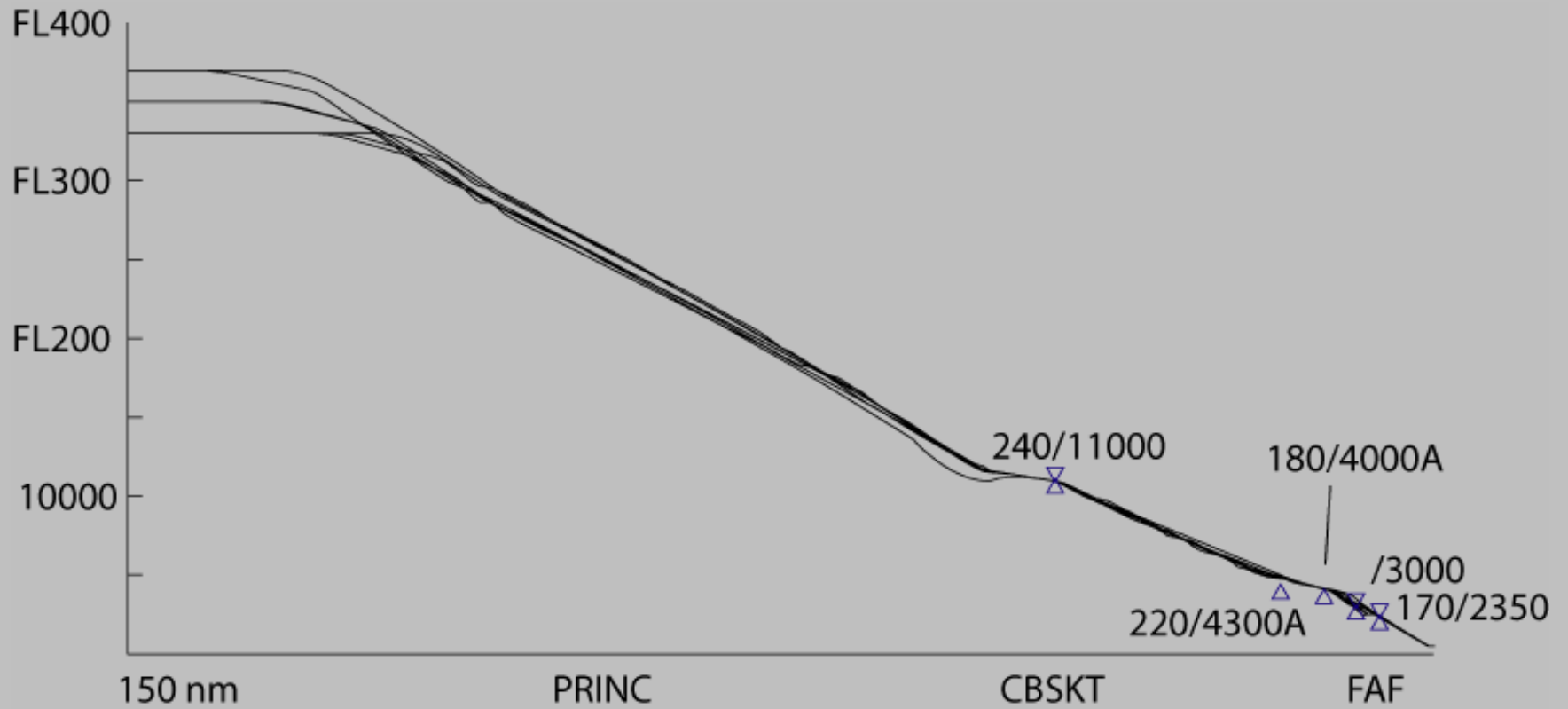
CHANGES: New Page.



# Example Scenario



# Vertical Profile



# Cockpit Display and Interaction



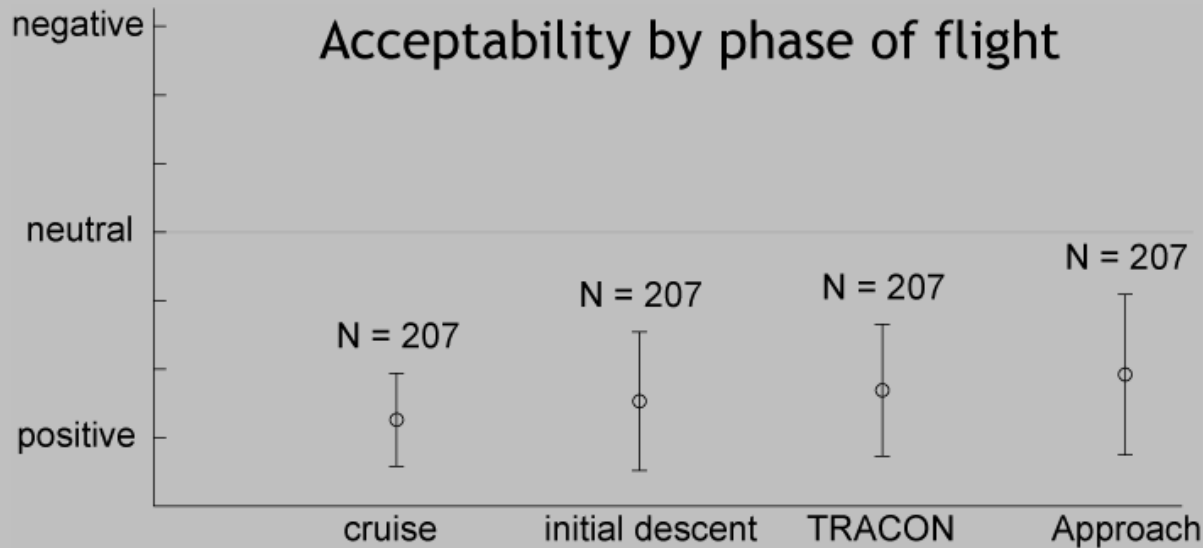
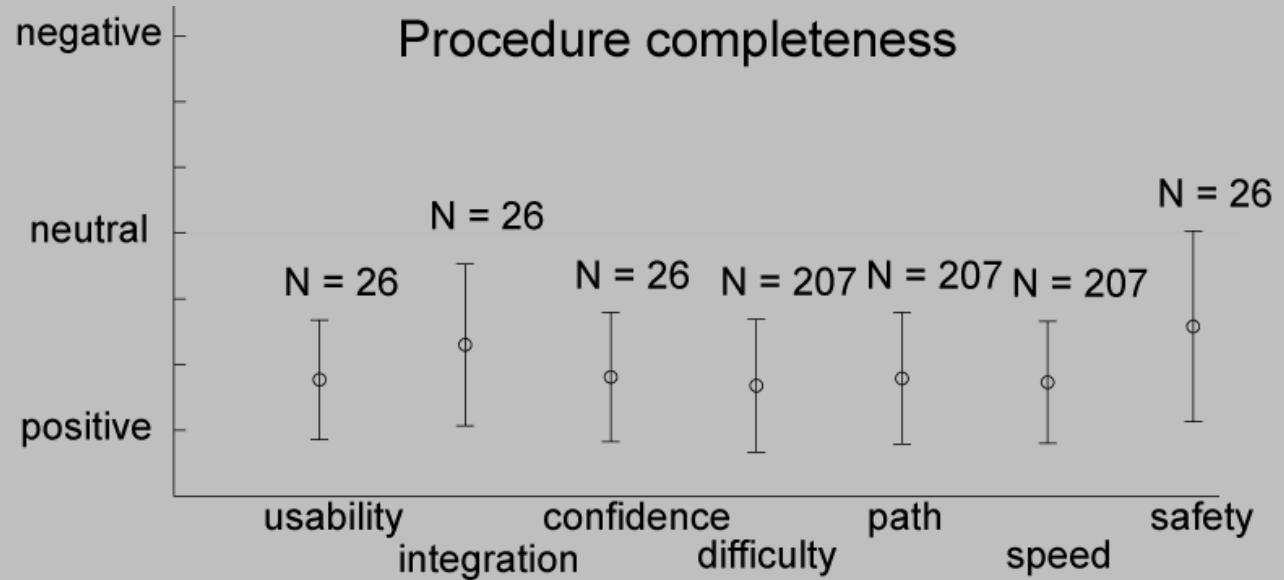
## Nominal Procedure

1. Enter **Lead AC ID** and **Spacing Interval** (from company, not ATC) through MCDU page
2. Verify or enter ownship final approach speed
3. When valid guidance is presented, open the speed window on the MCP and enter the displayed speed
4. Monitor PDS speed and make adjustments when new speed is guided including configuration changes
5. When checking-in on a new frequency, add "company spacing"  
*Louisville Approach, NA891, ..., company spacing*

# Procedures and Operations Feedback



All completeness and acceptability questions answered on a 7 point rating scale



Mean MCH\* workload rating of 1.87 ( $SD = 0.78$ ,  $N = 207$ ) indicated that instructed tasks were easy/desirable, mental effort was low, and desired performance was attainable (\* 10 point rating scale)

# Completeness and Correctness



65% of pilots said they had a complete set of procedures for the situations they encountered (94% reported no problems).

9 said “no,” primarily citing minor issues:

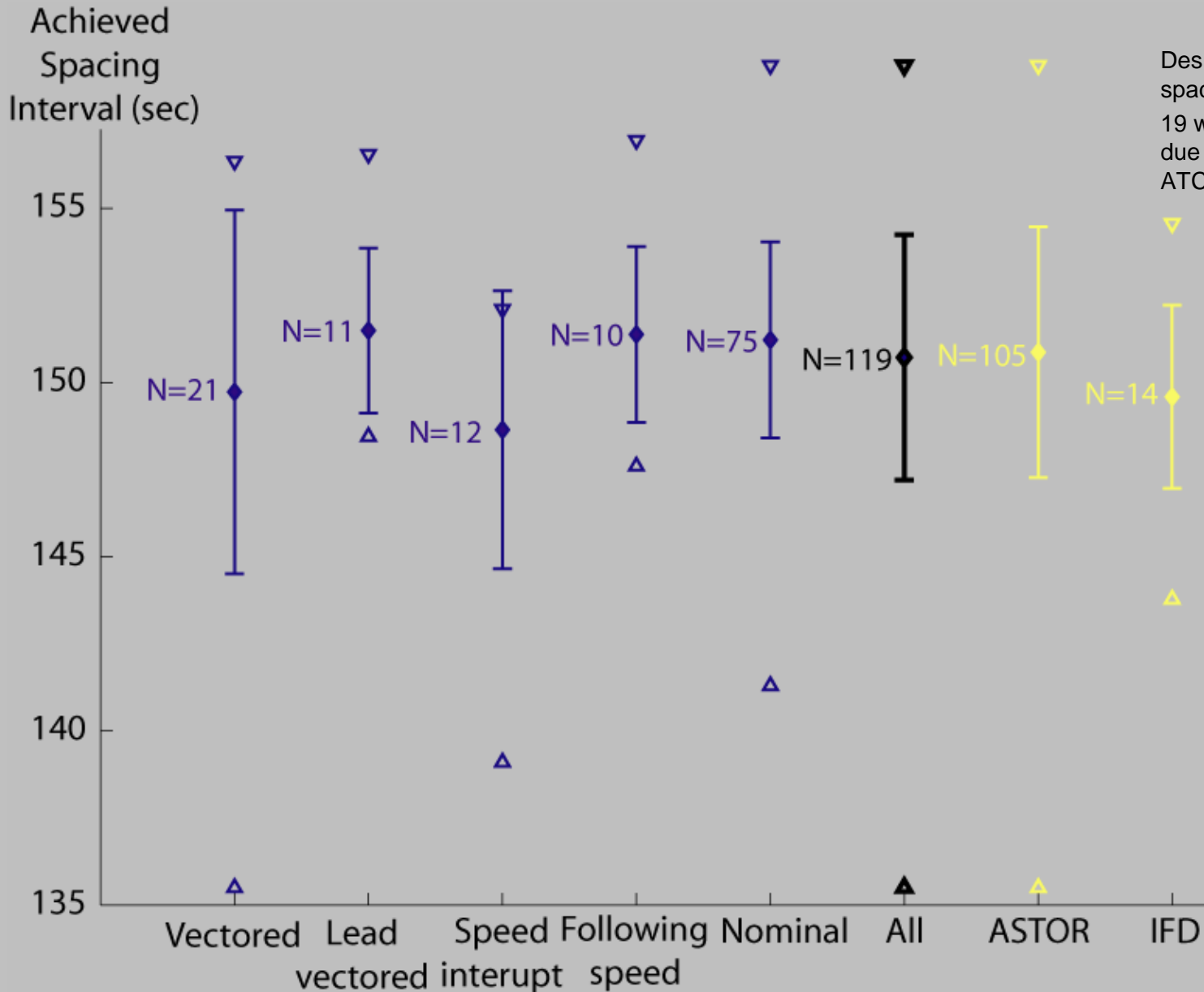
- 1 problem was an experiment procedure, not flight procedure
- 3 formatting suggestions were provided
- 1 instance of confusion with wording
- 1 comment that a one-step procedure was not on the card
- 1 disagreement with the resuming criteria
- 1 pilot said he was unclear which speed to fly when terminating
- 1 pilot was uncertain as to when the EXCESS SPC ERR procedure should be used

Only minor anomalies associated with the spacing procedures were detected.

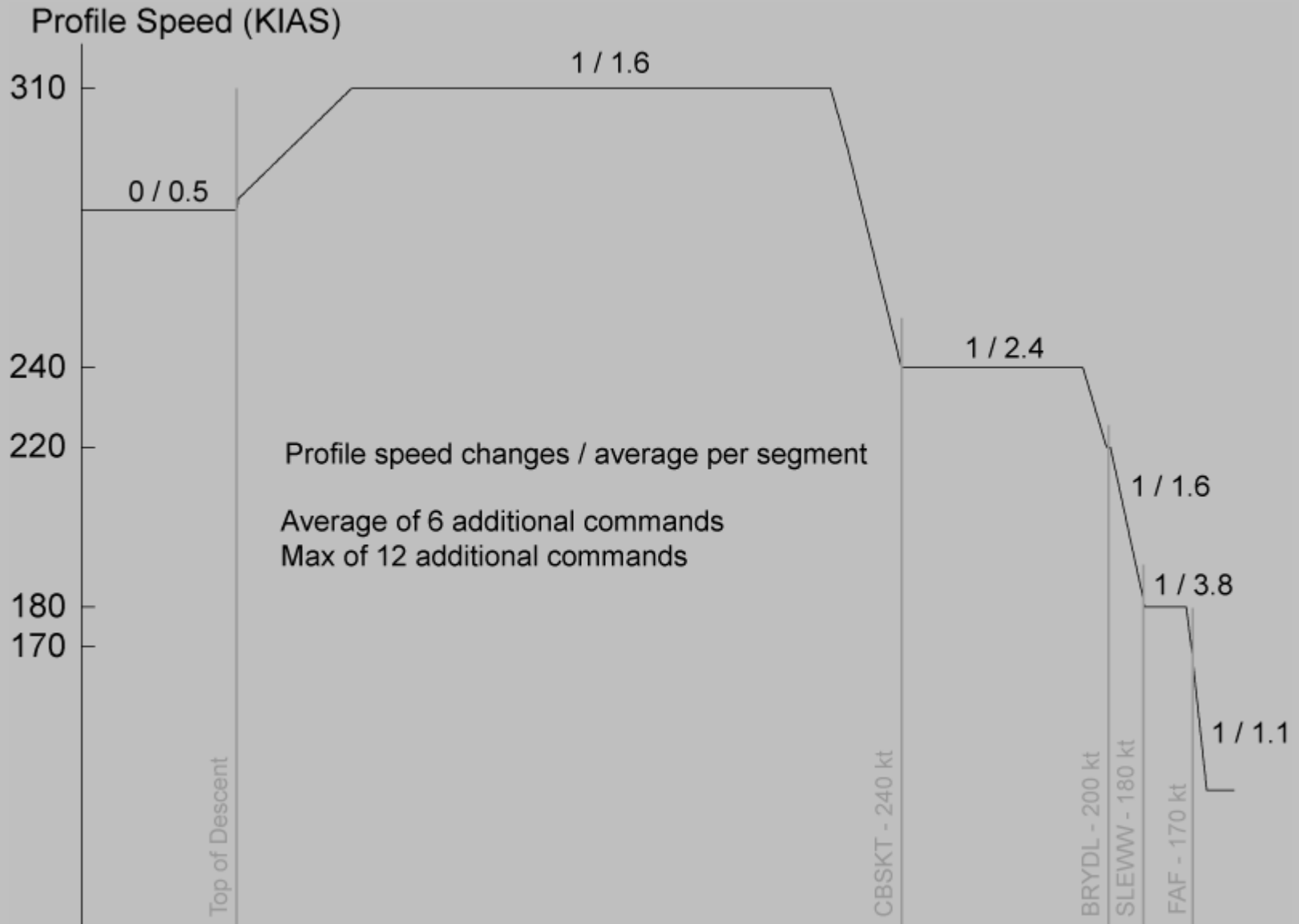
Variations on the phraseology



# Spacing Performance



# Location of Speed Changes



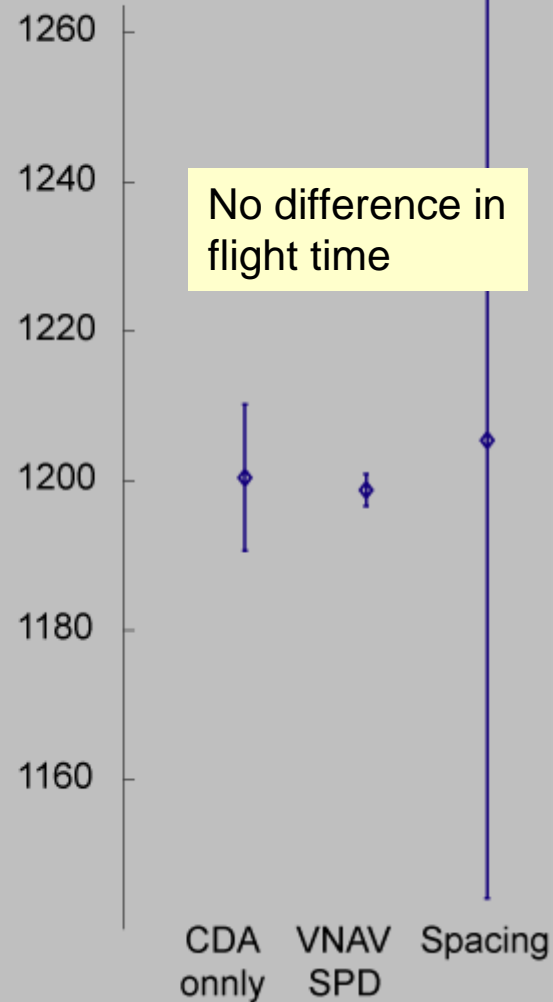
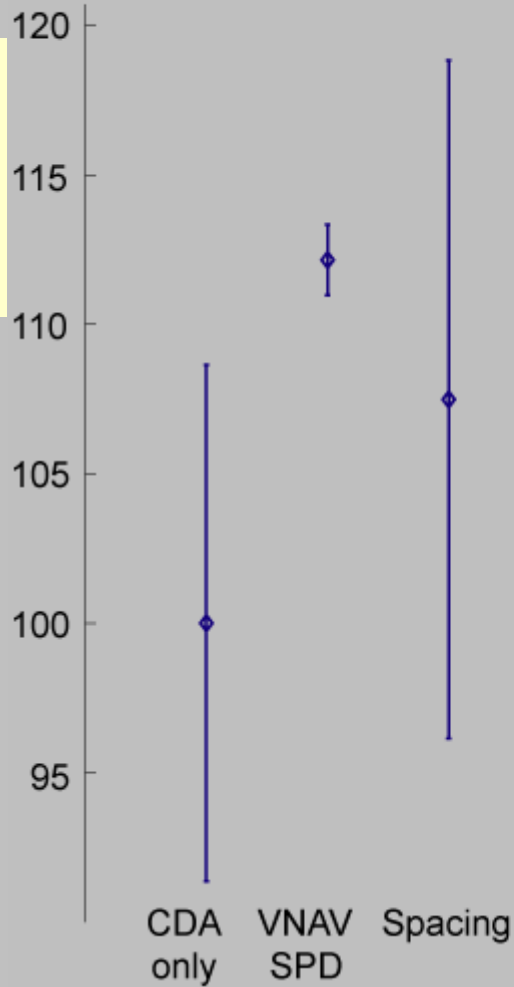


# Fuel and Time Savings

Fuel Usage (normalized)  
Last 110 nm flight distance

Flight Time (sec)  
Last 110 nm flight distance

More fuel burn for speed intervene (VNAV SPD and spacing) than VNAV PTH



No difference in flight time

Data only for single pilot station simulators

# *Conclusions*



Airborne spacing along Continuous Descent Arrivals was shown to be feasible and beneficial.

Pilots felt the procedures were complete, usable and could be incorporated into their other tasks.

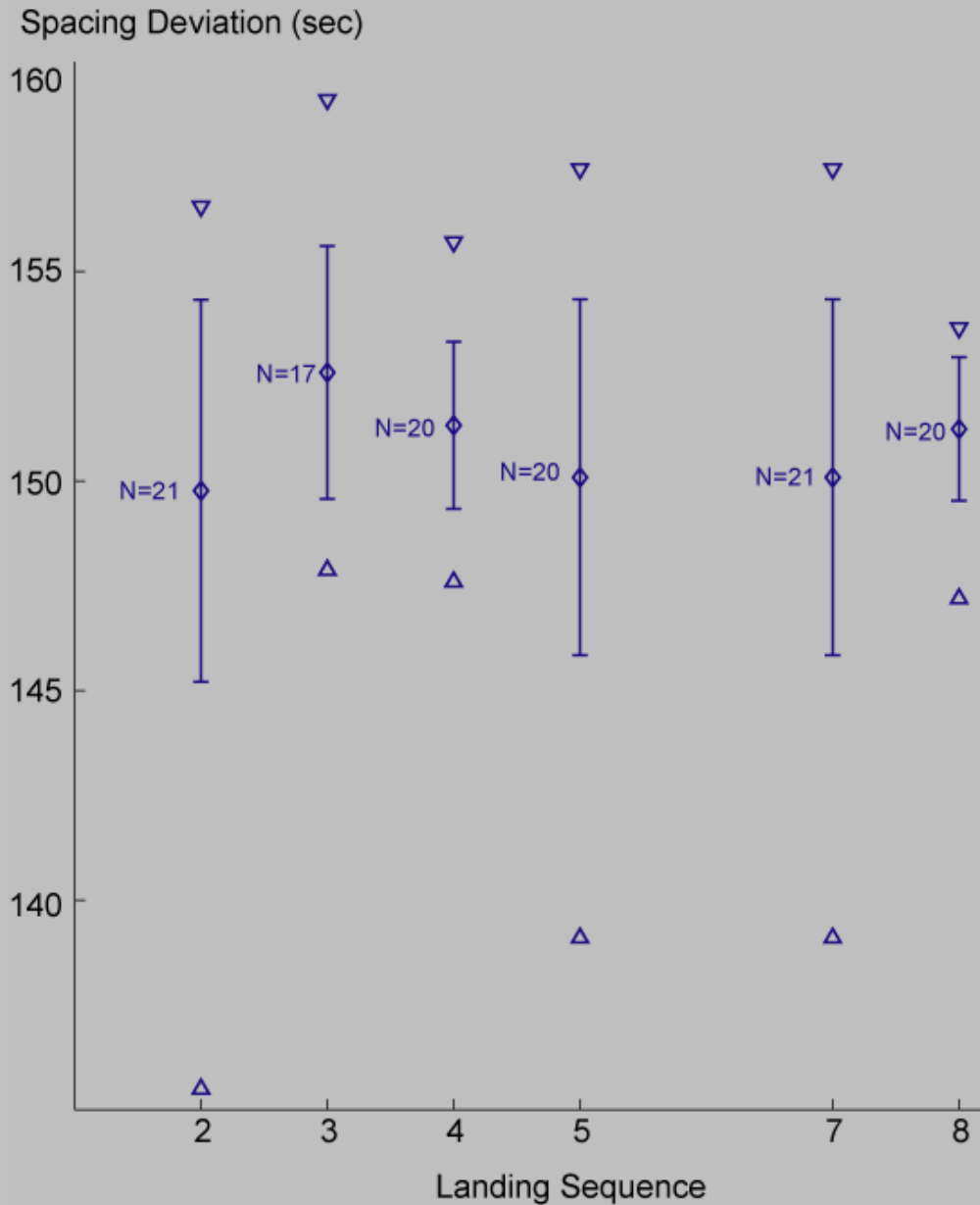
Aircraft were delivered within  $\pm 5$  seconds (1100 ft) with few outliers.

Approximately 6 additional speed adjustments were needed for spacing.

Airborne spacing had no impact on fuel burn or flight time.



# Stability of operation



No statistical dependence on location in the arrival flow